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HENRY AUGUSTUS ROWLAND.

By Joseph S. Ames.

In the death of Professor Rowland, of Johns Hopkins University, the science of Astrophysics has lost its foremost investigator and its greatest authority. It may not be too much to assert that the modern study of spectroscopy as an exact science dates from the beginning of Rowland's work; and the fact that so much has been accomplished during the past twenty years by students both at home and abroad bears witness to the impulse given to research and investigation by the force of his example and by the assistance of instruments furnished by his genius. Before noting in detail, however, what were the main contributions of Professor Rowland to the science to which this Journal is devoted, it may be well to record the leading features of his life.

Henry Augustus Rowland was born at Honesdale, Penn., November 27, 1848, the son of a Presbyterian minister. He received a good secondary education and entered the Rensselaer Polytechnic Institute, Troy, N. Y., from which he graduated in 1870, receiving the degree of "Civil Engineer." All of his inclinations as a boy were toward scientific work. He read with the greatest interest all the writings of Faraday and Tyndall,

and performed many chemical and physical experiments. He formed the habit at an early day of keeping accurate record not only of his observations, but also of the ideas which occurred to him from time to time. These notebooks are intensely interesting, and when Rowland's life is written, as it surely will be, they will throw the clearest light on his whole mental development. In these books are found numerous suggestions of investigations undertaken later by himself or others.

After a short experience, first as a member of a corps of railway engineers and then as teacher of general science in Wooster College, Ohio, Rowland returned to Troy as an instructor in the Polytechnic Institute, and was soon promoted to be assistant professor of physics. It was while at Troy that he performed his classical experiments on the study of the magnetization of iron. These established results and methods of investigation which are of fundamental importance. When Rowland had prepared for publication an account of his observations and theories, he sent it to an American journal; but it was returned as not suited for publication, the suggestion being made that the research was a rather presumptuous one for an unknown man to undertake, and that the paper would be improved if the theoretical part was removed. Rowland thereupon sent the manuscript to Professor Clerk Maxwell, of Cambridge, who acknowledged its receipt by saying he regarded it as of such importance that he had forwarded it at once to the *Philosophical Magazine*. One further incident in connection with this research, and one most characteristic of the man, should be recorded. He had little if any apparatus at his disposal and no laboratory rooms; so he constructed his own instruments and used the window seats of his bedroom for his laboratory piers.

In the spring of the year 1875 Mr. Gilman, who had just been elected president of Johns Hopkins University, was an official visitor at the United States Military Academy at West Point; and in talking one day to Professor Michie of that institution President Gilman mentioned the fact that he was looking for a man to take charge of the work in physics in the university

at Baltimore. Professor Michie was a connection of Rowland by marriage and was well acquainted with his work at Troy. At the former's suggestion Rowland was requested by President Gilman to come at once to West Point; and it was there that the two men met whose names are so indissolubly connected with the history of Johns Hopkins University and of education in America. Rowland's record at Troy as a teacher was not of the best, but President Gilman saw in him those qualities which were most needed as the director of a great physical laboratory. On his recommendation, therefore, the trustees of Johns Hopkins University invited Rowland to join their faculty, and gave him leave of absence for a year in which to go to Europe, with the idea that he should spend this time partly in buying apparatus and partly in becoming better acquainted with the laboratories of physics abroad and with their methods of work. Rowland spent the winter in Berlin, and took advantage of the facilities of Helmholtz's laboratory to perform his electrical convection experiment which established the fact that an electrical charge, if carried at a high speed, has the same magnetic action as an electric current. He then traveled from city to city on the continent purchasing apparatus — not for purposes of demonstration, but for use in researches and investigations: measuring apparatus of all kinds, standards of length and electrical resistance, etc. He returned to America in 1876, and began his work at Baltimore in the autumn as professor of physics.

Rowland's attention was first drawn to practical problems connected with electricity and to some theoretical questions which arose in connection with his lectures to his classes. He made a redetermination of the ohm; he measured the ratio of the electrical units; he investigated electric absorption of crystals; the Hall-effect was discovered. He then began his classical investigation on the subject of the "mechanical equivalent of heat," which resulted in his obtaining a prize offered by the Venetian Institute and also the Rumford medal given by the American Academy of Arts and Sciences. In this great research he made the first thorough study of the scientific

principles involved in the measurement of temperature and quantities of heat.

About 1881 he became interested in the subject of spectrum analysis, and realizing that the most important part of the necessary apparatus was the diffraction grating, he set himself the task of constructing a dividing-engine to be used for ruling gratings. At this time the best gratings available were those made by Mr. Rutherfurd, of New York; but they were far from being satisfactory. In the course of an investigation on the absolute wave-length of light, in which he used Rutherfurd gratings, Dr. C. S. Peirce had made a special study of the "ghosts," proving that they were due to periodic errors in the ruling of the grating. There were other errors, too, owing to the lack of uniformity in the pitch of the screw. In the dividing engine, as designed by Professor Rowland, both these sources of error were avoided as far as possible. He invented a process for cutting a screw which secured one of nearly perfectly constant pitch, and which is fully described in his article on the "Screw" in the *Encyclopædia Britannica*. He designed a method also for so moving the nut of the screw independently of the motion of the screw as would allow any periodic error—due to irregularities at the two ends of the screw—to be "corrected." This first dividing engine was arranged so as to rule 14438 lines to an inch; but machines constructed later ruled 20000 and 15000 to the inch. Having a ruling engine now at his disposal, the idea occurred to him to consider the effect of ruling the lines on a curved surface instead of a plane one, such as had always been used in the past. He attacked the problem mathematically, and discovered that a grating ruled on a spherical concave surface would have certain most distinctive properties: the spectrum could be maintained "normal" by a simple form of mounting, and always in focus along a certain line, without the use of lenses; the spectrum would be astigmatic; dust in the slit would cause no difficulty. Concave gratings were immediately made and were found to be perfectly satisfactory. When his own laboratory was supplied with the necessary gratings, others were ruled and were

distributed throughout the world. The immediate result was a most wonderful development of the science of spectroscopy and its applications.

Rowland himself had two great ideas or projects in regard to the use of the grating; to map the solar spectrum and to make a careful study of the metallic spectra. He saw the importance of having accurate measurements of both solar and metallic lines so as to serve as standards for reference and as means for verifying various solar or stellar theories; but the main reason for his interest in this prolonged investigation which lasted over so many years lay in the belief that by means of its conclusions some definite ideas might be deduced as to the nature of the molecules of matter. The measurement of spectrum lines as such was without the slightest interest to him; it was only when these measurements could be used in connection with some fundamental theory that they possessed value. "Where is the Kepler for molecules?" he would often say. It is hardly necessary to recall to the readers of this JOURNAL what Professor Rowland did for the science of spectroscopy in addition to the invention of the concave grating: the preparation of the wonderful map of the solar spectrum; the measurement of tables of "standard" lines, both solar and metallic, the measurement of the arc-spectra of the elements; the first theory of the diffraction grating which took into account the effect of the shape of the groove and the complete action of periodic errors.

It is well to recall, too, the difficulties under which Professor Rowland labored when he began his spectrum work, and the way he overcame them. He made his concave grating and its mounting, but was at first obliged to confine himself to eye-measurements. The art of photography was in its infancy. He had to flow his own plates and to learn how to sensitize them for different portions of the spectrum and how to develop them properly. This he did with great success. He further had to make a complete study of absorbing liquids so as to prevent the objectionable effects of overlapping spectra.

During the past few years Professor Rowland was interested

largely in the theory of alternating electric currents and in their application to motors, measuring instruments, and in particular to a multiplex printing telegraph system which achieved a most striking success at the Paris Exposition of 1900.

Only a word need be said in regard to the last days of his life. He was ill from a nervous disorder during the months of January and February, but then recovered sufficiently to return to his duties and work at the laboratory. After a few weeks, however, he was again confined to his home by a trivial illness, when suddenly he was taken critically ill and died within twenty-four hours, on the morning of Tuesday, April 16. He had known for more than ten years that his end would come as it did; and the realization of this fact was always in his mind. The manner in which he hid it from others and went on his life's way was but one of many illustrations of his self-control and bravery.

Professor Rowland's services to science were recognized both at home and abroad, as is shown by the list of honors which came to him. Among the societies to which he was elected are these:

FOREIGN

The British Association for the Advancement of Science.
The Physical Society of London.
The Philosophical Society of Cambridge, England.
The Royal Society of London.
The Royal Society of Göttingen.
The Gioenian Academy of Natural Sciences, Catania, Sicily.
The French Physical Society.
The French Academy of Sciences.
The Literary and Philosophical Society of Manchester.
The Royal Lyncean Academy, Rome.
The Academy of Sciences, Stockholm.
The Italian Society of Spectroscopists.
The Royal Society of Edinburgh.
The Society of Arts, London.
The Royal Astronomical Society of England.
The Royal Society of Lombardy.
The Royal Physiographic Society of Lund.
The Royal Academy of Sciences, Berlin.

AMERICAN

The American Philosophical Society, Philadelphia.
The American Academy of Arts and Sciences, Boston.
The National Academy of Sciences, Washington.
The American Physical Society — its first president.

His academic degrees were these:

Civil Engineer (C. E.), Rensselaer Polytechnic Institute, 1870.
Doctor of Philosophy (hon.) (Ph.D.), Johns Hopkins University, 1880.
Doctor of Laws (LL.D.), Yalé University, 1895.
Doctor of Laws (LL. D.), Princeton University, 1896.

Among other distinctions may be named:

Officer of the Legion of Honor of France.
Rumford Medallist of the American Academy of Arts and Sciences.
Draper Medallist of the National Academy of Sciences.
Matteucci Medallist (Italian).
Recipient of the prize of the Venetian Institute, for his work on the Mechanical Equivalent of Heat.

Delegate from the United States government to the

International Congress of Electricians, Paris, 1881.
International Congress for the Determination of Electrical Units, Paris, 1882.
Electrical Congress, Philadelphia, 1884 — President.
International Chamber of Delegates for the Determination of Electrical Units, Chicago, 1893 — President.

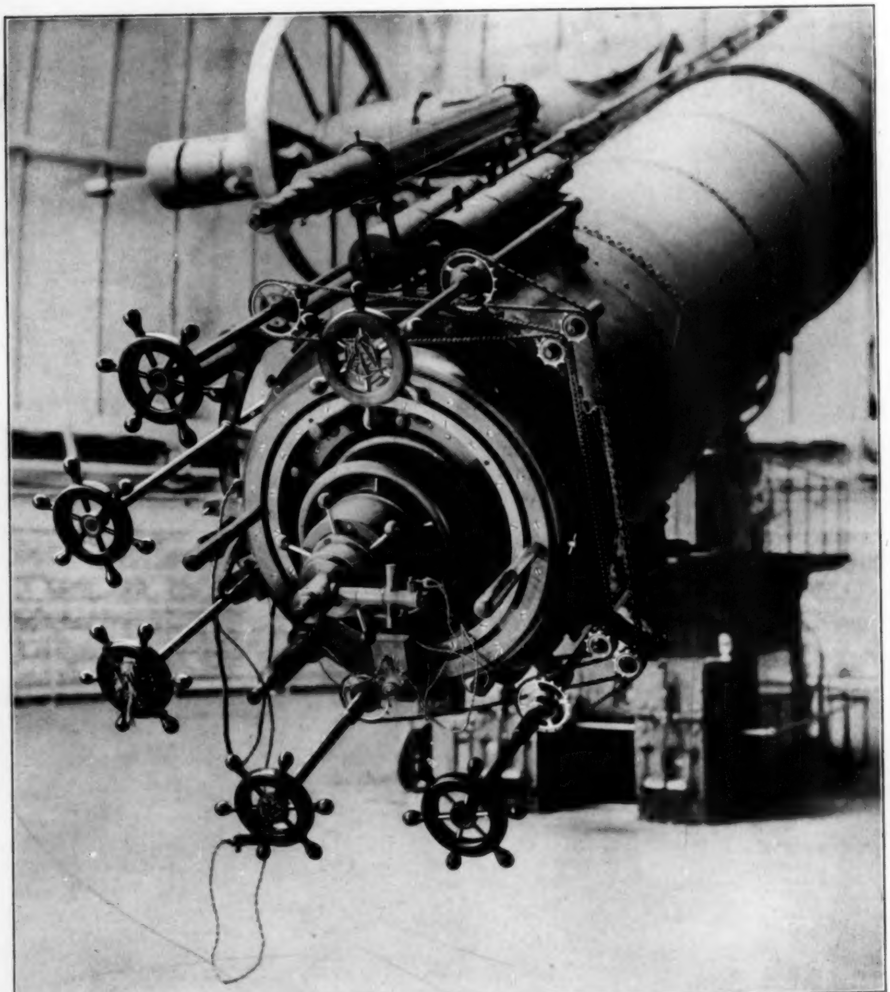
Even if one takes into account the inventions and discoveries of Professor Rowland and his many scientific researches, it is not upon these alone, or even in the main, that his reputation and renown rest; they are not his greatest gift to the world. Much more important than any of his individual pieces of work was his influence on his generation by his spirit, his aims, and through the many students and associates who came to know and appreciate him. It is quite impossible to estimate the effect he has had on all branches of science, both theoretical and practical. His most striking qualities of mind were clear vision, absolute self confidence, simplicity, generosity, moral courage. His intuitive knowledge of physical laws was simply marvelous; and his assurance in his own judgment was complete. It was largely

owing to these qualities that he accomplished what he did. The suggestions as to theoretical or experimental work which he offered in the course of his daily lectures were always of the greatest help to his students; and his criticisms of their work or of that of others were even more so. He was continually inspiring his students to aim at the highest ideals, not to be satisfied with ordinary things. The great simplicity and truthfulness of his character made him beloved by every one who came near him. He was generous to a fault in his life as a citizen and always took most seriously his civic duties.

He was interested intensely in everything pertaining to the improvements of his city.

The loss to science in America, occasioned by his death, cannot be estimated, it can be only dimly felt. It is a personal one to everyone who worked with him or who knew him and even to those who have merely seen him. There is no one to take his place.

PLATE VII



STELLAR PHOTOMETER ATTACHED TO 40-INCH YERKES TELESCOPE

DETERMINATION OF THE WEDGE CONSTANT OF A STELLAR PHOTOMETER.

By J. A. Parkhurst.

In pursuance of a plan for coöperation in determining standards for faint stellar magnitude, Professor E. C. Pickering sent to the Yerkes Observatory in April 1900, one of the five wedge photometers which he had devised for the work. This was to be used with the 40-inch refractor in the measurement of the faintest stars included in the plan. The construction of the instrument is shown in Fig. 1 and Plate VII, and will need but few words in description. The tube *T*, carrying the ocular *O*, slides into the tailpiece of the telescope. At right angles to this is the tube *C*, carrying the essential parts of the photometer. The light from a 1½ candle-power incandescent lamp *L* shines through a minute hole in the diaphragm *D* upon a piece of ground glass *G*, forming an artificial star. In contact with *G* is a piece of blue glass to render the light of the star less yellow. An image of this star is thrown by the projecting lens *P* upon a plate of plane-parallel glass *B* and reflected from both surfaces into the focus of the ocular *O*, forming at *E* and *F* two images of the artificial star. Interposed in the path of these rays is the photographic wedge *W*, movable at right angles to *C* by the rack and pinion *R*. The short tube carrying the ground glass *G* is movable away from the diaphragm *D* by means of the head of the screw *S*, projecting through an inclined slot in the farther side of the tube *C*. By this means the artificial star can be made larger and less sharply defined, thus resembling more closely a real star under poor atmospheric conditions. Finally, a pair of shade glasses at *A* can be moved, either both or singly, into the path of the rays.

In photometers made on this principle the all-important condition to be fulfilled is that the images of the real and artificial stars should closely resemble each other. The range of

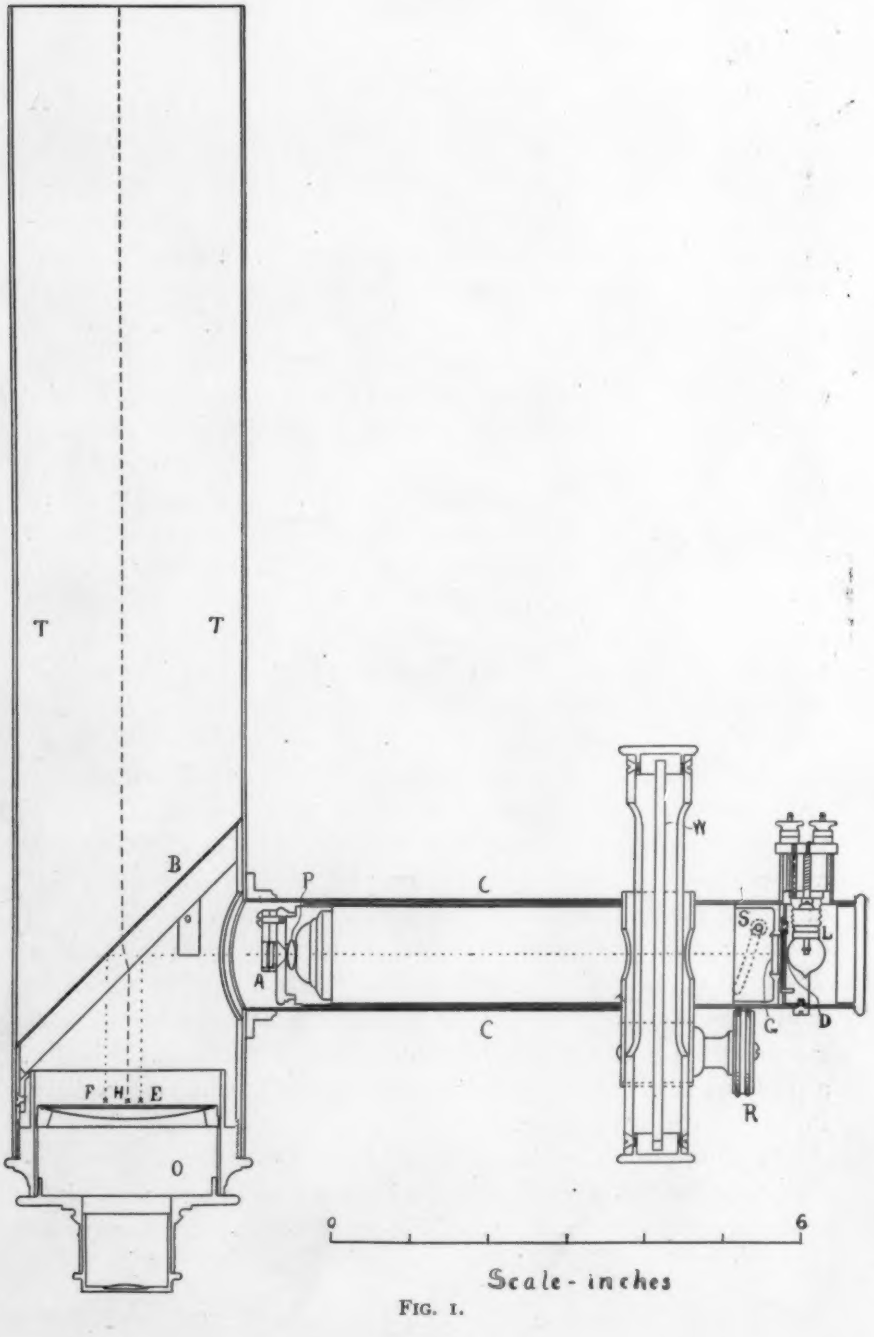


FIG. 1.

adjustment of the ground glass *G* was found to be insufficient to meet this condition with the different telescopes on which the photometer was to be used; therefore the diaphragm *D*, originally provided, which had a single aperture 0.17 mm in diameter, was replaced with a movable diaphragm carrying three apertures, 0.11, 0.20, and 0.30 mm in diameter. By choosing the most suitable aperture and combining with it a slight movement of the ground glass, it was possible to give the disk of the artificial star any required size and sharpness, to suit the various telescopes used, and the different atmospheric conditions.

In order to use the photometer with a 6½-inch reflector and a 2-inch refractor, a smaller tube was provided carrying an ocular and a diagonal reflecting plate to replace *B*. After several trials good images of the real and artificial stars were given by a diagonal plate with surfaces correct to $\frac{1}{10}$ of a wave-length, furnished by Mr. O. L. Petitdidier of Chicago.

The use of this instrument is very simple and convenient. The image of the star to be measured (shown at *H* in the drawing) is brought between the two images of the artificial star and the wedge is moved by the pinion *R* till the light of the real star is matched by *E*, the image formed by reflection from the first surface of the plate *B*. The position of the wedge is then read on a scale divided to twenty-fifths of an inch, tenths of a division being estimated. If now the light of a star of known magnitude be measured, the only unknown quantity is the "constant of the wedge," the value of one division of the scale expressed in magnitudes.

The methods available for determining the wedge constant can be classed under two heads: (1) Measurements of standard stars whose magnitudes have been well fixed; (2) measurements of an artificial star whose light can be reduced by a known amount either by (*a*) polarization, (*b*) a revolving wheel, (*c*) reduced apertures by stationary diaphragms. The last method can be used either with real or artificial stars. The method by standard stars seems to give the best results, as it has the great advantage that the measurements are made under precisely the

same conditions as in actual practice; therefore the main dependence was placed upon it. Under (2) the reduction of apertures by stationary diaphragms seems to give the least reliable results, so was not used. As no proper polarizing photometer was available the choice was restricted to (*b*), the "wheel photometer," consisting of a revolving disk out of which sector-shaped openings were cut.

MEASURES WITH THE "WHEEL PHOTOMETER."

This arrangement consisted of an artificial star formed in a manner similar to the photometer star, by a small incandescent lamp, diaphragm, oiled paper (found to be a good substitute for ground glass), and a piece of the same blue glass used with the photometer lamp, thus insuring stars of the same color. Half an inch from the blue glass was placed the "wheel," a brass disk out of which were cut two opposite sectors, either of which could be covered by black photographic paper. The wheel was turned by clockwork at a speed of about forty revolutions per second. The wheel could be moved out of the path of the rays, giving the light of the wheel lamp unreduced. This position is called "sector off" in Tables I and II, "sector on" indicating that the light was cut down by the revolving wheel. The photometer was placed with the tube T pointing at the wheel, and the diagonal plate B 30 inches from the wheel. The light of the wheel star was focused by an achromatic lens of 1 inch aperture, inserted in the tube T.

Table I gives a specimen set of measures made in the following order (both sectors E and F being uncovered). With the wheel out of the path of the rays ten settings in the first column were made, then the wheel was turned into the path, the clockwork started and the ten settings in the second column were made, and so on, the quantities recorded being the readings of the wedge scale.

For the accurate values of the sector angles used in the reductions I am indebted to the kindness of Dr. E. S. Johonnott, of the Rose Polytechnic Institute, Terre Haute, Ind., who measured the angles on an excellent circular dividing engine made by the Société Genévoise.

It is evident that the ratio of the unreduced to the reduced light is that of 360° to the combined sector angles, in this case 20° 42'.68, and that this ratio can be expressed in difference of magnitudes by dividing its logarithm by 0.4. The reductions are given in detail at the foot of Table I; the difference in scale readings, 24.03 divisions, corresponding to a difference of 3.100 magnitudes, from which the value of one scale division, which is the wedge constant *C*, is found to be 0.1290 magnitudes.

In Table II are collected the results of thirteen sets of measures made with the "wheel photometer," each quantity in the second and third columns being the mean of ten settings of the wedge. Columns 4 and 5 give the difference between the unreduced and reduced light, expressed in scale divisions and magnitudes, respectively; column 6 gives the resulting value of *C*, which, with equal weights, give the mean value 0.1283 mag, with a probable error of 0.0008 mag.

TABLE I.

SPECIMEN SET OF MEASURES WITH "WHEEL PHOTOMETER."

1900 November 22, sectors E and F.

	Off	On	Off	On	Off
	d	d	d	d	d
	16.0	36.5	13.9	41.6	15.5
	16.2	39.2	15.2	40.4	17.0
	14.9	40.7	17.0	40.0	16.9
	16.3	40.4	16.8	41.0	16.8
	17.1	39.0	15.9	41.4	17.9
	16.2	41.2	18.0	41.5	16.2
	17.2	41.4	15.7	39.0	15.5
	16.9	40.8	15.9	41.0	15.0
	16.5	40.4	17.0	40.9	16.8
	16.9	39.5	16.4	41.3	16.4
Means.....	16.42	39.91	16.18	40.81	16.40

	Off	On	Sectors E and F
	d	d	
Means -	16.33	40.36	Angle = 20° 42'.68

$$\text{Log ratio } \frac{360^\circ}{20^\circ\ 42'.68} = 1.2402$$

$$\frac{\text{Log ratio}}{0.4} = \Delta\text{ M} = 3.100$$

Result, Δ d = 24.03, Δ M = 3.100, C = 0.1290 mag.

TABLE II.

RÉSUMÉ OF MEASURES WITH "WHEEL PHOTOMETER."

Sectors	Means		Δd	ΔM	C	No. of settings
	Off	On				
	d	d			M	
E & F........	10.48	35.08	24.60	3.100	0.1260	30
E & F........	16.33	40.36	24.03	3.100	.1290	50
F............	16.66	45.52	28.86	3.629	.1257	15
F............	14.72	43.09	28.37	3.629	.1280	30
E & F........	13.82	37.83	24.01	3.100	.1291	50
E & F........	13.67	36.38	22.71	3.100	.1365	50
E............	13.70	47.20	33.50	4.136	.1235	50
E & F........	13.31	36.68	23.37	3.100	.1326	50
E & F........	17.56	40.87	23.31	3.100	.1330	50
E & F........	17.89	42.29	24.40	3.100	.1271	50
E & F........	15.03	38.81	23.78	3.100	.1304	50
F............	14.67	43.82	29.15	3.629	.1245	50
E............	15.12	48.98	33.86	4.136	0.1222	50
Mean					0.1283	
P. e........					± 0.0008	

CONSTANTS OF SECTORS.

Sector	Angle	Log ratio $\frac{360°}{\text{Angle}}$	Log ratio / 0.4
E	478°.62	1.6545	4.136
F	764.06	1.1514	3.629
E & F	1242.68	1.2402	3.100

MEASUREMENTS OF STANDARD STARS.

Advantage was taken of Müller and Kempf's excellent "Determination of the Brightness of Ninety-six *Pleiades* Stars,[1] which furnished a conveniently placed list of well-determined standards. It was found by experiment that the best results were obtained by comparing bright stars between magnitudes 6 and 8, with faint ones between magnitudes 9.5 and 10.5. The stars used are collected in Table III, which gives the list number, approximate place for 1900, and magnitude; all taken from Müller and Kempf's list. Table IV is a specimen set of these measures, made with the 6-inch reflector, and the Petitdidier diagonal plate. Four settings were made on a bright star and faint star alternately. In this case the measures began with star

[1] *A. N.*, **150**, 193.

No. 25 in M. and K.'s list, and the four settings are given in the first line, followed by "Mean d," the mean of the scale readings; and the star's magnitude according to M. and K. The ninth column gives the difference between the "Mean d" for this star and the faint star in the following line; the tenth column the corresponding difference in magnitude; the eleventh the resulting value of C. Column 12 gives the difference in magnitude computed with $C = 0.1334$ mag. (the mean value from the *Pleiades* measures), and the last gives the difference between this and M. and K.'s Δ M.

The measures of the *Pleiades* stars are collected in Table V, for which the headings of the columns are self-explanatory, except that the last column gives the number of nights on which the pairs were measured. Weighting the values of C according to the number of nights, gives the mean value 0.1334 mag. The probable error 0.0004 mag. is obtained, not from the values of C in this table, but from the eighty-four separate results of a single night's measure of the different pairs. No correction has been made for change in zenith distance, since the series begin and end with a bright star.

TABLE III.

MÜLLER AND KEMPF'S *PLEIADES* STARS USED IN DETERMINING WEDGE CONSTANT.

	1900				1900		
No.	R. A.	Dec.	Mag.	No.	R. A.	Dec.	Mag.
	h m s				h m s		
IV	3 39 57	+24° 15'	6.17	55	3 41 15	+23° 28'	9.57
14	43 1	23 33	6.72	56	42 10	23 50	9.58
15	40 5	24 13	6.75	57	44 16	24 22	9.63
17	44 2	23 33	7.10	58	40 43	23 48	9.65
V	41 2	24 13	7.15	60	39 45	23 59	9.70
19	41 32	23 59	7.18	61	41 13	23 58	9.76
20	42 33	24 3	7.23	64	39 42	24 19	10.00
21	41 22	23 25	7.24	66	41 56	23 38	10.06
22	44 56	23 40	7.28	67	44 1	23 39	10.08
23	41 25	23 30	7.31	VIII	43 34	24 20	10.14
25	41 28	23 36	7.53	71	42 3	23 48	10.20
26	40 30	22 57	7.63	72	42 29	23 45	10.21
27	44 30	24 12	7.78	73	42 22	23 20	10.29
29	43 59	24 3	7.84	74	42 9	23 4	10.31
VI	3 41 26	+24 17	7.99	75	40 42	23 29	10.35
				76	39 39	23 46	10.36
				77	41 5	24 20	10.42
				79	3 42 22	+23 35	10.52

TABLE IV.

SPECIMEN SET OF MEASURES OF *PLEIADES* STARS.

1900 Nov. 15, 23 h. Sid. T.

With 6-inch reflector, aperture reduced to 4½ inches

Z	Star	Scale readings				Mean d	M. & K. Mag.	Δd	ΔM	C	ΔM P	M. & K. —P.
									M	M	M	M
53°	25	18.0	19.4	19.2	19.4	19.00	7.53					
	71	38.6	38.0	37.5	38.8	38.23	10.20	19.23	2.67	0.1388	2.57	+0.10
	V	16.7	15.7	16.1	16.8	16.33	7.15	21.90	3.05	1393	2.92	+ 13
	77	43.0	43.2	42.8	42.8	42.95	10.42	26.62	3.27	1228	3.55	− 28
	VI	20.5	21.1	21.3	21.7	21.15	7.99	21.80	2.43	1115	2.91	− 48
	76	40.2	40.0	40.1	39.8	40.03	10.36	18.88	2.37	1255	2.52	− 15
	19	15.3	16.2	15.0	16.8	15.83	7.18	24.20	3.18	1314	3.23	− 5
	79	41.8	41.2	39.4	41.1	40.88	10.53	25.05	3.34	1333	3.34	00
	21	15.0	15.2	15.9	16.0	15.53	7.24	25.35	3.28	1294	3.38	− 10
	73	42.0	40.4	40.6	39.3	40.58	10.29	25.05	3.05	1218	3.34	− 29
	23	17.8	18.0	18.2	19.0	18.25	7.31	22.33	2.98	1334	2.98	00
	72	37.9	39.4	38.0	38.6	38.48	10.21	20.23	2.90	1434	3.00	− 10
	25	19.6	17.7	19.2	18.5	18.75	7.53	19.73	2.68	1358	2.53	+ 15
	74	39.8	39.7	39.9	39.9	39.83	10.31	21.08	2.78	1318	2.81	− 3
	20	15.9	15.9	17.0	15.9	16.18	7.23	23.65	3.08	1303	3.14	5
	75	38.0	40.9	40.0	39.0	39.48	10.35	23.30	3.12	1339	3.11	+ 1
	21	16.5	17.2	17.2	17.0	16.98	7.24	22.50	3.11	1382	3.00	+ 11
	76	38.2	41.0	39.1	39.3	39.40	10.36	22.42	3.12	1392	2.99	+ 13
	V	15.6	15.3	16.0	15.2	15.53	7.15	23.87	3.21	1345	3.18	+ 3
	72	37.0	40.2	38.0	39.3	38.63	10.21	23.10	3.06	1325	3.08	− 2
43	VI	20.0	23.0	21.6	21.7	21.48	7.99	17.05	2.22	0.1302	2.27	−0.05

TABLE V.

MEASURES OF *PLEIADES* STARS.

Pairs	Δd	ΔM M. & K.	C	ΔM P	M. & K.—P.	No.
			M	M	M	
V-71	22.64	3.05	0.1348	3.02	+0.03	3
V-77	25.46	3.27	.1285	3.40	− .13	4
V-VIII	23.04	2.99	.1299	3.07	− .08	4
19-VIII	23.49	2.96	.1261	3.13	− .17	2
19-76	23.40	3.18	.1360	3.12	+ .06	4
19-74	23.81	3.13	.1316	3.18	− .05	4
19-72	22.63	3.03	.1337	3.02	+ .01	4
19-77	24.19	3.24	.1339	3.23	+ .01	2
20-VIII	21.59	2.91	.1349	2.88	+ .03	2
20-71	21.17	2.97	.1404	2.82	+ .15	2
20-72	21.46	2.98	.1389	2.86	+ .12	4
21-73	23.20	3.05	.1318	3.09	− .04	5
21-79	24.55	3.28	.1337	3.27	+ .01	5
23-75	22.98	3.04	.1324	3.06	− .02	4
23-79	24.55	3.21	.1309	3.27	− .06	4
25-73	20.55	2.76	.1345	2.74	+ .02	4

TABLE V.—*Continued.*

MEASURES OF *PLEIADES* STARS.

Pairs	Δd	ΔM M. & K.	C	ΔM P	M. & K.—P.	No.
			M	M	M	
25–74	20.97	2.78	.1327	2.80	− .02	5
25–75	20.94	2.82	.1349	2.79	+ .03	4
25–76	20.41	2.83	.1388	2.72	+ .11	4
V–76	23.87	3.21	.1345	3.18	+ .03	1
V–72	23.10	3.06	.1325	3.08	− .02	1
19–79	25.05	3.34	.1333	3.34	.00	1
20–74	23.65	3.08	.1303	3.15	− .07	1
20–75	23.30	3.12	.1339	3.11	+ .01	1
21–75	22.50	3.11	.1382	3.00	+ .11	1
21–76	22.42	3.12	.1392	2.99	+ .13	1
23–72	20.23	2.90	.1434	2.70	+ .20	1
23–73	22.33	2.98	.1334	2.98	.00	1
25–71	19.23	2.67	.1388	2.56	+ .11	1
25–72	19.73	2.68	.1358	2.63	+ .05	1
VI–72	17.05	2.22	.1302	2.27	− .05	1
VI–76	18.88	2.37	.1255	2.52	− .15	1
VI–77	21.80	2.43	.1115	2.91	− .48	1
Means			0.1334 ±0.0004		0.10	

TABLE VI.

PAIRS OF STARS FROM THE *POTSDAM PHOTOMETRIC DURCHMUSTERUNG*, PART I.

Pairs	Settings		Mags.		Δd	ΔM	C	R
	d	d				M	M	d
2306–00	14.13	40.38	4.42	7.73	26.25	3.31	0.1261	0.65
2368–87	12.02	40.48	4.10	7.64	28.46	3.54	.1244	.70
2430–35	12.37	34.47	4.17	6.62	22.10	2.45	.1109	.47
2439–17	11.74	36.13	4.00	7.02	24.39	3.02	.1238	.65
2415–03	15.39	36.28	4.23	7.04	20.89	2.81	.1345	.39
2581–78	16.43	35.93	4.44	7.28	19.50	2.84	.1456	.64
2879–77	11.12	32.98	3.90	6.37	21.86	2.47	.1130	.90
2875–78	18.49	37.78	4.85	7.48	19.29	2.63	.1302	.60
2875–66	18.49	37.83	4.85	7.24	19.34	2.39	.1236	.62
Means							0.1158	0.62 d
P. e							0.0024	

Table VI gives the results of measures of nine pairs of stars taken from the *Potsdam Photometric Durchmusterung*, Part I.

For these measures a Brashear objective of 2.1 inches aperture was used with the photometer in its original form. The order of settings was: (1) four on the bright star; (2) eight on the faint star; (3) four on the bright star. The table gives in the successive columns the *P. DM.* numbers of the stars of the pair, the mean of the settings on the bright and faint stars, their magnitudes, the difference in scale readings and magnitudes, the resulting value of *C*, and the mean residual of the separate settings from the mean of eight.

Table VII gives the details of a single night's measures of six of the comparison stars for the variable *7792 SS Cygni*,

TABLE VII.

MEASURES OF COMPARISON STARS FOR *7792 SS CYGNI.*

1900 June 14, with 12-inch refractor.

	Settings				Means		
					1st	2d	R.
	d	d	d	d	d	d	d
b	16.8	14.2	15.2	16.6	15.70	15.17	1.00
c	24.0	23.8	23.5	23.3	23.65	23.22	25
a	26.8	26.2	24.7	26.8	26.13	26.02	69
d	32.2	33.7	31.9	32.8	32.65	32.78	60
p	33.3	34.2	35.0	34.3	34.20	32.90	45
m	37.8	38.3	38.9	37.0	38.00	38.59	60
m	39.1	38.1	39.5	40.0	39.18		58
p	30.5	31.8	31.1	33.0	31.60		80
d	33.0	32.8	32.6	33.2	32.90		30
a	24.9	26.5	26.4	25.8	25.90		55
c	20.8	23.9	22.5	23.9	22.78		1.13
b	13.4	15.1	15.6	14.4	14.63		0.73
Mean							0.64

whose magnitudes were kindly communicated to me by Professor E. C. Pickering.[1] Four settings were made on each of the six stars, then these were repeated in reverse order. Column 6 gives the mean of each set of four, column 7 the mean of the eight settings on each star. The method of deducing the value of *C* is given at the foot of the table.

[1] For the positions and notation of the comparison stars see the ASTROPHYSICAL JOURNAL, **12**, 260.

Table VIII collects the final results of these measures. The mean value

$$C = 0.1300$$

is obtained by weighting the separate determinations according to the number of settings. It would seem to be reliable within two or three units in the third decimal place. The last two columns of the table give the average residual of the separate settings from the mean of four, eight, or ten as the case may be.

RESULTS.

By comparing the mean settings and magnitudes of the three brighter stars, *a*, *b*, and *c*, with those of the three fainter stars, *d*, *m*, and *p*, we have

	d	M		d	M
b	15.17	8.50	*d*	32.78	10.92
c	23.22	9.39	*p*	32.90	10.90
a	26.02	9.62	*m*	38.59	11.17
Means	21.47	9.17		34.76	11.00

$\Delta d = 13.29$, $\Delta M = 1.83$, $C = 0.1377$.

TABLE VIII.

FINAL RESULTS FOR VALUE OF THE WEDGE CONSTANT.

	C	No. of settings	P. e. of mean	Mean R.	
	M		M	d	M
Wheel photometer	0.1283	575	0.0008	0.71	0.09
Pleiades stars	0.1334	360	0.0004	42	05
P. DM. stars	0.1258	136	0.0024	62	08
Comparison stars for *SS Cygni*	0.1377	48		0.64	0.08
Weighted mean	0.1300				

In conclusion I may say that this form of photometer is certainly very convenient in use, and seems to give good results. It has the advantage over other forms of wedge photometers that the light of the real star does not pass through the wedge, thus avoiding the danger of systematic errors arising from star colors.

YERKES OBSERVATORY,
March 1901.

ON THE TYPES OF SUN-SPOT DISTURBANCES.

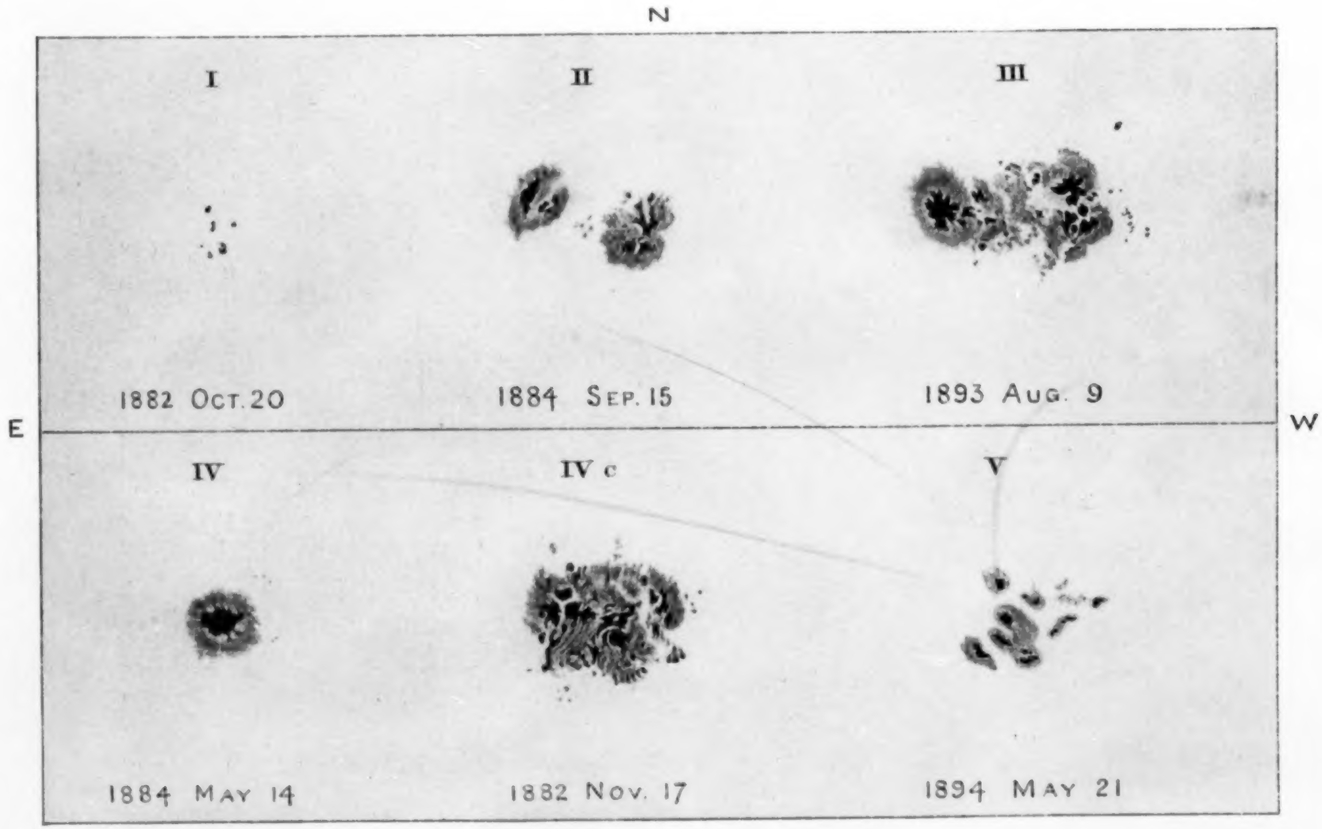
By A. L. CORTIE, S.J.

As AN aid to researches connected with Sun-spots an attempt is made in the present paper to classify them according to some prevailing typical forms. Descriptions of the varying phases presented by a group of Sun-spots are generally and necessarily somewhat verbose, and one aim of the present attempt at classification is to be able, by a succession of type numbers, to succinctly describe the various phases in the life-history of a spot-group. These classes cannot pretend to describe in minutest detail all the varying aspects presented in the life-history of a group of Sun-spots, but their most salient features can be succinctly represented by them. The classification adopted in this paper is merely tentative, and is submitted as such to the criticism and discussion of solar observers. It has been derived from a study of some 3500 drawings of Sun-spots secured at the Stonyhurst College Observatory during the last twenty years.

Among the groups represented upon these drawings, 296 were selected for discussion, belonging to 117 either greater Sun-spot disturbances, or disturbances in some way connected with these greater outbursts. By a greater disturbance is meant one which during any part of its life-history covered an area of $\frac{1}{1000}$ of the Sun's visible hemisphere. A full list of such disturbances is given in a paper recently read before the Royal Astronomical Society (*Monthly Notices*, Vol. LX, No. 8, May 1900).

The Stonyhurst drawings show that spots appear as scattered groups of small spots, as trains of spots, as composite groups consisting of three or more larger spots, as single spots of round and regular outline, which may or may not be accompanied by smaller companions, and as single spots of irregular outline, either accompanied by a train of smaller companions, or with outliers not arranged in the form of a train.

PLATE VIII



TYPES OF SUN-SPOTS

The chief type, however, of which the above mentioned are in most, possibly in all, cases but phases, is the double spot formation, with a train of smaller spots between the two principal spots of the group, the whole group generally drifting into more or less parallelism with the solar equator. In this form the principal spot, which eventually becomes a normal spot of regular outline, is generally the leading spot, but in many cases it is the following spot, while sometimes the preponderance in area alternates between the two, as the group traverses the disk. In yet rarer instances both the chief spots develop as regular spots. The following are the types which will probably be found to cover most cases that may arise:

Type I. A group of one or more small scattered spots.
Type II. The two-spot formation:
- II*a*. In which the leader is the principal spot.
- II*b*. In which the following spot is the principal spot.
- II*c*. In which both spots are more or less equal.

Type III. A train of spots:
- III*a*. With well-defined principal spots.
- III*b*. Without well-defined principal spots, but consisting mostly of penumbral patches with shattered irregular umbra.

Type IV. Single spots:
- IV*a*. A single spot of round and regular outline.
- IV*b*. A single spot of round and regular outline with small companions.
- IV*c*. A single spot of irregular outline.
- IV*d*. A single spot of irregular outline with a train of smaller companions.
- IV*e*. A single spot of irregular outline with smaller companions not in a train.

Type V. An irregular group of larger spots.

In most cases it is comparatively easy to assign Sun-spots to the various types selected, but in some the line of demarcation is not very marked, and consequently it becomes more difficult to do so. For instance, Type IV*d* approximates very often to II*a*. The order of types has been chosen as indicating the succession of phases through which a normal Sun-spot disturbance generally passes.

The first type covers the period of the birth of a Sun-spot group which almost invariably appears as a few small scattered dots, surrounded by flecks of brilliant faculæ. Whether these flecks of faculæ precede or follow the first appearance of the dots, is yet an unsettled point. The weight of evidence, however, seems to favor the first supposition. These scattered dots next coalesce into two principal spots, as indicated by Type II, the preceding spot of the couple being generally the more compact, while the following spot presents a broken appearance, though in many cases it may cover a larger area than its fellow. The space between these two spots begins to fill up with a train of smaller spots, the process being completed in 5 to 7 days after the birth of the group. This phase is represented by Type III. In a few days the train of spots between the two principal spots disappears, the process being followed in most cases by the disintegration of the following of the pair of principal spots. This leads to the stage represented by Type IV, where the group consists mainly of a single spot, generally of a round and regular outline, with the penumbra arranged symmetrically about a densely black central umbra. This single spot may, however, be of quite irregular outline—witness, the great spot of February 1892—and each of these subclasses, again, may or may not have accompanying smaller spots. In the great majority of cases it is the leading spot which becomes round and regular, and which also, during the earlier stages in the life of the group, frequently has a very rapid forward proper motion in longitude. The cases in which the following spot of the group, which often in the earlier stages of the life-history of the group is of far greater area than the leader, develops into a round spot are comparatively rare (*e. g.*, 1892, July 4–October 5). However, instances occur in which both spots become round spots (*e. g.*, 1881, October 14, December 17). The stage of a single round spot lasts frequently for two solar rotations, and has in one case (1897, April 28–August 27) been recorded during five successive rotations. In some cases the single spot gradually decreases in

size, until it becomes a mere dot, when other small spots will spring up around it, and the cycle of phases will be again repeated (*e. g.*, 1886, March 29–September 15).

During the earlier stages of the life-history of a Sun-spot group the faculæ are intensely bright and cling closely to the component members of the group. As the group grows in age, the faculæ gradually extend, until during the single spot stage of the group and its evanescence, they cover a very considerable area. With their greater extension they lose their brilliancy. Even when the spot has finally disappeared, the faculæ may remain extended in the same region of the Sun for two or more rotations. In the scheme of classification submitted the gradual dying away of a spot is represented as a recurrence to Type I, especially in view of the repetition of the cycle which then sometimes supervenes. Irregular groups of larger spots have been put into a class apart, Type V. Allowing for the necessary imperfection of our record, on account of days when it was impossible to secure drawings, the prevailing types are IV, II and I, arranged in provisional order. It would seem, too, from a study of the material at hand, that the ordinary process of spot-formation and life-history could be represented by the following sequence of types: I, II*b*, II*a*, III*a*, II*a*, IV*d*, IV*a*, I.

One advantage of describing the life-history of a spot-group by means of these type-numbers is that it indicates fairly accurately the age of a spot. Thus a group marked II is in the earlier stages of its life, while one marked III*a* is, at the most, ten days old, while one marked IV*a* is at least thirteen or fourteen days old. Two examples will suffice to illustrate the application of these type numbers.

The first was a spot-group seen during seven rotations, from 1886, March 29–September 15, its mean heliographic positions being longitude 71° and latitude —10°.

The separate rotations are denoted by vertical lines: 1, 2*b*, 1, 3*b* | 1, 2*b* (April 29) 2*a* | 4*a* | 4*a*, 4*c* | 1, 2*a* | 4*c* | 1 | . The

second was a composite group which was born and died on the visible disk, and was seen from 1887, May 14–September 4, in mean position longitude 92, latitude —8°. Its history reads thus: 1, 2*b*, 3*a* | 4*b*, 4*a* | 4*d*, 4*a* | 4*a*, companion 1, 2*a* | 1 | . In this case the companion group did not appear until the fourth rotation.

STONYHURST COLLEGE OBSERVATORY,
September 4, 1900.

PLATE IX

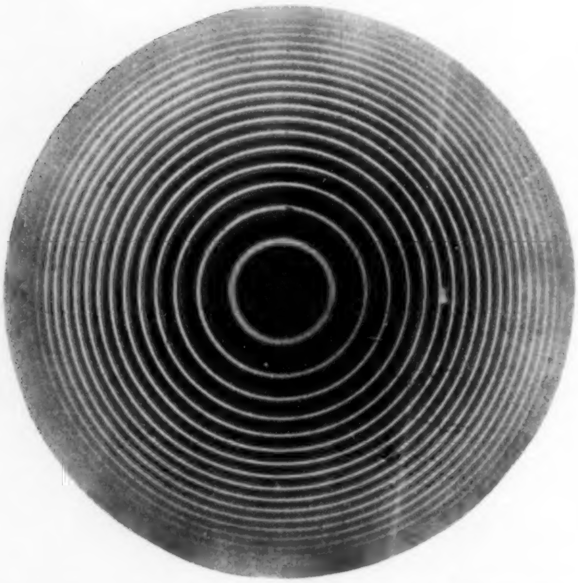


FIG. 1.—INTERFERENCE FRINGES OF GREEN MERCURY LINE

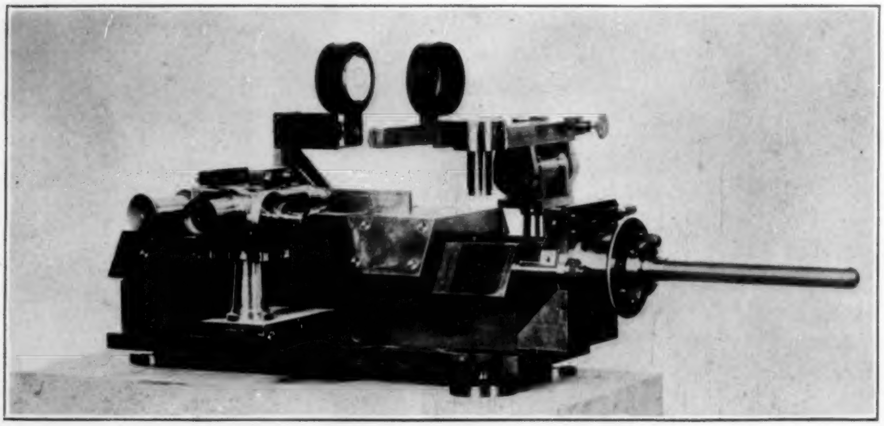


FIG. 2.—NEW FORM OF INTERFEROMETER

ON A NEW FORM OF INTERFEROMETER.[1]

By CH. FABRY and A. PEROT.

In a series of memoirs[2] published by us during the last three years we have described various applications of fringes produced by silvered plates. The special properties of these fringes will, in our opinion, render possible a notable extension of the already wide field comprising the applications of interference fringes. The applications which we have already described relate to the optical measurement of lengths, to the comparison of wave-lengths, and to spectroscopy.

All of these experiments have been made with apparatus which we have constructed with no aid from the instrument-maker other than that required in preparing plane glass surfaces. These are the instruments, ordinarily of very simple construction, which we have described in the memoirs already referred to. These instruments, improvised for the occasion in order to avoid serious loss of time, necessarily contain various imperfections. We have always taken care to conduct our experiments in such a way as to avoid the influence of these imperfections on the accuracy of the results. A characteristic feature of our methods is that the observer has constantly before his eyes, in the very appearance of the phenomenon under observation, a proof that the adjustments are rigorously exact. But imperfections of the apparatus nevertheless make the preliminary steps in

[1] Translated from an advance proof from *Annales de Chimie et de Physique*, communicated, with additions and illustrations, by the authors.

[2] "Sur les franges des lames minces argentées et leur application à la mesure des petites épaisseurs d'air." (*Ann. de Chim. et de Phys.*, 7e série, t. XII, p. 459; 1897.) "Théorie et applications d'une nouvelle méthode de spectroscopie interférentielle." (*Ibid.*, 7e série, t. XVI, p. 115; 1899.) "Méthodes interférentielles pour la mesure des grandes épaisseurs et la comparaison des longueurs d'ondes." (*Ibid.*, 7e série, t. XVI, p. 289; 1899.) "Sur les sources de lumière monochromatique." (*Journ. de Phys.*, 3e série, t. IX, p. 369; 1900.) "Électromètre absolu pour petites différences de potentiel." (*Ann. de Chim. et de Phys.*, 7e série t. XIII, p. 404; 1898.) "Mesure du coefficient de viscosité de l'air." (*Ibid.*, 7e série, t. XIII, p. 275; 1898.)

A brief résumé of these investigations was published in the ASTROPHYSICAL JOURNAL, Vol. IX, p. 87, February 1899.

every investigation much more troublesome, and may even render impracticable an application which would be easily effected with a more perfect instrument.

These considerations have led us to order from M. Jobin an interferometer suitable for the convenient observation of the phenomena of silvered plates, and consequently for the realization of the various applications described in our papers. This apparatus, which has been constructed in a most perfect manner, is described in the present article.

The greater part of our applications of the interference phenomena of silvered films depend upon interference at great difference of path, produced by transmission through two plane surfaces, rigorously parallel, with transparent silver surface; the interference rings are observed by means of a telescope focused for parallel rays. These conditions determine the essential parts of the interferometer with silvered plates; they consist simply of two plane surfaces, provided with all necessary means of adjustment for orientation and displacement. It must be possible to adjust their relative orientation and particularly to render them rigorously parallel. Their distance must be susceptible of varying from contact up to 10 cm; it is very convenient to have this displacement effected by an exactly parallel motion in such a way as to preserve the parallelism of the surfaces. It must be possible, during this parallel displacement, to stop at any desired distance within a few thousandths of a micron, but displacements of several centimeters must not require too much time. This leads to the use of three different rates of adjustment: (1) rapid motion; (2) motion slow enough to permit the fringes to be counted; (3) displacement by flexure through a range of a few microns, as slow and as delicate as may be desired.

Similarly, there are two distinct adjustments for orientation: a quick motion of great amplitude for approximate adjustment, and a very slow motion of orientation of small range, produced by flexure.

The adjustments by flexure are all obtained by the pressure

on pieces of steel of small rubber bags filled with water and connected by means of a long rubber tube to a funnel containing water whose height can be varied; by changing the height a variable force is applied by means of the bag upon the piece of steel against which it presses. This arrangement has the following advantages: the bag being wider than the metallic piece against which it presses, the tension of the rubber does not enter

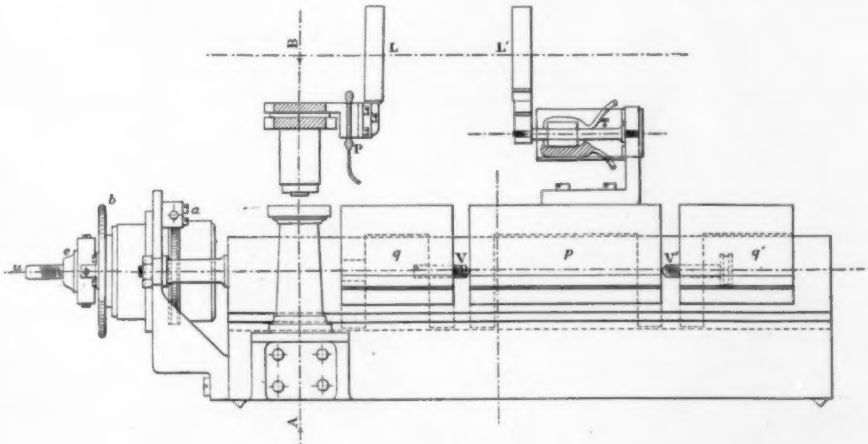


FIG. 1.

and the force depends only upon the pressure exercised by water; as this is defined by the height of the funnel, there need be no fear of a change in the adjustment from this cause during the progress of the work. Moreover, the pressure may be varied as slowly as is desired, and with this arrangement absolutely perfect adjustments are obtained; it may be added that the pressures are produced without giving any shock to the system, which is indispensable in order to avoid any disarrangement.

These are the essential elements of the instrument. Let us now proceed to the detailed description.

L, *L′* (Fig. 1) are the two plate-carriers in which the silvered plates are supported; each of these is a disk 40 mm in diameter with projecting shoulder, by means of which it can be fastened in the plate-carrier without danger of distortion. The silvered

face is rigorously plane, the reverse only approximately so. The two faces are not parallel, but make with each other an angle of about $1'$, to prevent interference in a single plate, which would interfere with the phenomenon under observation.

The plate-carriers have the following adjustments: *L*, toward the observer (Fig. 2), may be given quick motions for orientation and very small parallel displacements. The first of these motions is obtained by rotation about two axes, one of them vertical, *O*, the other horizontal, *O'*, as in a theodolite. The small parallel displacement is produced by bending a strong steel spring *P* (Figs. 1 and 2), attached at its middle point to the theodolite axis *O* on one side, and to the plate-carrier on the other; this spring consists of two steel bars 16 cm long by 2 cm wide and 4 mm thick, connected at their two extremities *E* and *E'* by means of metal plates. The rubber bag used to produce the displacement is shown in position in the cuts. A change of 1 cm in the height of the funnel produces a parallel displacement of 0.15μ. The total range employed has never exceeded 20μ.

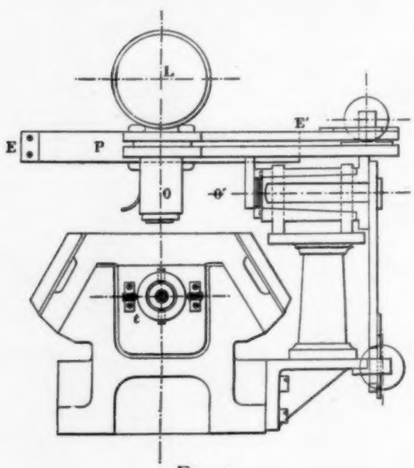


FIG. 2.

The plate-carrier *L'* (Fig. 1) may be given fine adjustments for parallelism and large parallel displacements, either rapid or slow. *L'* is carried at the extremity of a steel shaft *T* rigidly held at the other end, on which is fitted a bronze block, against which two rubber bags press in two directions at right angles to each other. A displacement of one centimeter of each of the corresponding funnels produces an angular displacement of $0'.25$.

To obtain perfect parallelism it is frequently necessary to adjust the height of the funnels within a millimeter.

Finally, large parallel displacements are obtained by means

of a bronze carriage on guides, p (Fig. 1), the bearing surfaces of which are worked with great accuracy. The displacement of the carriage is not produced by operating directly upon it; for this purpose it is placed between two shorter carriages, q, q', rigidly fixed with respect to each other; it may be moved by these in either direction by means of butting screws V, V', bearing on suitable points, which allow a little play. p is thus always free on the guides, where it rests by its own weight, and is acted upon when in motion only by forces parallel to the displacement, which produce no tendency to rock; it is doubtless on account of this device that it is possible to follow the fringes even when the carriage is moving. The two carriages q, q', are connected to a screw u whose head t (Fig. 2) is attached by a Cardan suspension, of which the nut e (Fig. 1), susceptible of rotation only, is also carried by a Cardan suspension. Lateral strains due to imperfect centering are thus avoided. There can thus be transmitted to the principal carriage only such impulses as are exactly longitudinal. The nut e can be moved rapidly by a milled head b or slowly by a tangent screw a. In the latter case one turn of the screw corresponds to about 15 fringes; it is possible to count the fringes.

It is very convenient to be able to quickly determine at any time the distance between the two silvered surfaces within a few microns; a scale divided to fifths of a millmeter is provided for this purpose, attached to the carriage p, and read by a microscope with micrometer eyepiece fastened to the bed of the apparatus. One division of the head equals $1\,\mu$. The zero is determined by setting the two surfaces at a known and easily calibrated distance; for example, that which corresponds to the first resolution of the two yellow lines of mercury (40μ).

Finally, to prevent vibrations the apparatus is carried on a small table hanging by four rubber cords, whose points of support are adjustable so as to permit the apparatus to be leveled.

A solid body[1] whose dimensions are to be determined is suspended between the interferometer plates in such a way that its

[1] *Ann. de Chim. et de Phys.*, 7 ser., **16**, 289.

faces can be made parallel to those of the silvered glass planes. The form of the support depends upon the dimensions of the solid body; it is always such as to permit displacements in distance or in inclination. In certain cases, such as the measurement of the quartz cube employed in the determination of the kilogram, perfect parallelism could be obtained through flexure produced by the rubber bags. The apparatus itself does not include this support and it is not represented in the figures.

Such, in general, is the new interferometer constructed by M. Jobin; it will be seen that it is especially adapted for the observation of interference fringes at great difference of path and for the applications of these phenomena. It is evident that it may also be employed to produce the phenomena of thin plates in parallel light; it is only necessary to put the plates a short distance apart and to give them the desired angle by means of the corresponding adjustments; the distance can then be varied without changing this angle.

It is also very easy to observe *superposition fringes* in white light, the numerous applications of which we have already indicated. If the fringes of thin plates[1] are desired the silvered surfaces of the interferometer are placed a short distance apart and upon the thin layer of air thus obtained there is projected the image of a *standard film*, which may be easily constructed by placing two surfaces of silvered glass in contact. By varying the path at a uniform rate by means of the tangent screw of the apparatus the various systems of fringes which correspond to the various simple ratios of the two thicknesses of air will be seen to appear successively. In this way at least ten systems of fringes in white light, easily distinguished from one another by their appearance, can be observed successively.

If thick layers are to be employed[2] both must have parallel surfaces which must be capable of orientation with reference to each other. One of these layers will be in the interferometer itself; the other may be a layer of air with parallel faces at a

[1] *Ann. de Chim. et de Phys.*, 7 ser., **12**, 459.

[2] *Ann. de Chim. et de Phys.*, 7 ser., **16**, 289.

fixed distance apart. We have constructed such layers and named them *standards of thickness*.[1] For experiment we have constructed in the laboratory standards of thickness varying from 0.25 cm to 12 cm. Fig. 3 represents a 1 cm standard made by M. Jobin. It consists of a steel plate A pierced by a circular opening in which are fastened three small steel screws P, the ends of which are carefully rounded and polished. Against these three curved surfaces plates of plane silvered glass L, L', are held by Brunner spring clamps, and are thus maintained at a fixed distance. By carefully scraping the steel pins the silvered plates are brought to perfect parallelism. Experience has shown that after dismounting and replacing the glass plates their parallelism is preserved and the thickness of the standard does not change.

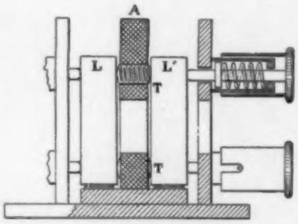


FIG. 3.

If then a convergent beam of monochromatic light is passed through the standard the phenomena of thick silvered plates will be visible. The adjustment of the standard, begun by the observation of multiple images, is completed by observation of the rings themselves. When the thickness exceeds about 20 cm the fringes in monochromatic light are no longer visible, and it becomes necessary to employ other methods which will be described later.

For the observation of superposition phenomena this plate is carried by an adjustable support standing beside the interferometer.

The use of these superposition fringes permits the interferometer surfaces to be set always at the same distance (that of the standard or one of its multiples or submultiples); this distance will be exactly known if the standard has been measured. It is thus possible to graduate the scale of the interferometer by investigating the various intervals successively and moving along the scale. Conversely, the fringes permit the measurement in wave-lengths of a constant standard, either by a direct

[1] *Comptes Rendus*, 130, 492, 1900.

determination on the interferometer or by two sets of measurements if its length is too great for the first method.

We believe that the applications of these fringes are far from being exhausted. They adapt themselves to the most varied combinations. As an example we may cite the possibility of measuring in a single operation the sum or difference of two different lengths which may or may not be capable of direct comparison, or any quantity of the form $pe+p'e'$, p and p' being small positive or negative integers. We shall have occasion to return to these various applications at some future time. In our present investigations the apparatus which M. Jobin has constructed in such perfection is proving itself to be of the greatest service.

Fig. 1, Plate IX, is a photograph of interference rings obtained with this apparatus, corresponding to the green mercury line ($\lambda=5460.7424$) given by the mercury arc in a vacuum. The distance between the silvered surfaces was only 5 mm. Although this distance was so small the complex constitution of this radiation is clearly shown: each bright ring is accompanied by a fainter first interior ring, by a second interior ring, which is much fainter still, and finally by an exterior ring, which is double.[1] Each of these rings indicates the presence of a faint radiation which accompanies the principal line.

The existence of these complex radiations has been announced by Michelson, but we believe that hitherto no spectroscopic apparatus has permitted them to be *seen* and their position in the spectrum to be fixed without any hypothesis. Our interferometer permits this to be done, and thus probably constitutes the most powerful spectroscope hitherto constructed. The resolving power of this spectroscope increases with the distance between the silvered plates, and can thus be increased as long as the fringes remain visible; the finer the lines examined the further can the resolution be carried; in other words, the power of the apparatus is in every case sufficient to show the finest details that it is possible to distinguish.

University of Marseilles,
January 1901.

[1] Unfortunately the delicate details of the original photograph are lost in the reproduction.—Eds.

MINOR CONTRIBUTIONS AND NOTES

VARIABILITY IN LIGHT OF *EROS*.[1]

THE discovery by Dr. Oppolzer that the light of *Eros* is variable suggests some photometric problems of great interest. If, as seems probable, we assume that the variation is due to the rotation of the planet, we can, from measures of its light, determine the time of rotation, and the direction in space of the axis of rotation. Owing to the varying position of the observer with regard to the planet, much information can be obtained which is impossible in the case of a variable star.

Four corrections must be applied to the observations. First, for the velocity of light; second, for the distance of the Sun and Earth; third, for phase; and fourth, for the direction of the axis of rotation. If this axis were pointed toward the observer, no variation would be perceptible, while the range in brightness would attain its maximum value when the axis was at right angles to the line of sight. Neither of these conditions can be fulfilled exactly, since the position of the axis is probably nearly fixed, and the inclination of the orbits of *Eros* and the Earth would make great changes in this angle. Let p represent the complement of the altitude of the Earth above the equator of *Eros*, which will be equal to the angle between the axis of *Eros* and the direction of *Eros* as seen from the Earth. Let v denote the angle between the plane passing through the Earth and the axis of *Eros*, and any other plane passing through the axis of *Eros*, assumed as an origin. A most important correction depends upon v. The time of all the observations must be corrected by an amount equal to v divided by $360°$ and multiplied by the period of variation. As a first approximation, we may assume that the axis of *Eros* is parallel to that of the Earth, and that the plane passing through the vernal equinox is taken as an origin. In that case, v will equal the right ascension of *Eros*. As stated above, if $p=0°$ there will be no variation in light, and the range will be zero. If $p = 90°$, the range will attain its maximum

[1] *Harvard College Observatory Circular* No. 58.

value. For intermediate values of p, we may assume that the range will be proportional to $\cos p$. The changes in the range may be used to determine the value of p, and from it the position of the axis of *Eros*. Equations may be formed in which p and v, or p alone, are the unknown quantities from which we may derive the approximate position of the axis. Besides observations at the present time, it will be necessary to determine the light curve when *Eros* is in several other portions of the sky, determining the range and also the times of maximum and minimum as accurately as possible. The rapid motion of *Eros* renders it difficult to compare the observations on different nights, without using different, and in some cases, distant comparison stars. Fortunately, the change in light is so rapid that consecutive observations of a large part of the light curve can generally be made. The opposition of 1894 would have been particularly favorable for these studies, since the declination changed from $+57°$ to $-14°$ in a few months, and would thus have furnished large coefficients for determining the value of p, although, as shown below, the range seems to have been small at that time.

Assuming that the variation in light of *Eros* is due to its rotation, two explanations may be offered, as in the case of variable stars of short period (*Proc. Amer. Acad.*, 1881, XVI, 257). First, that *Eros* is darker on one side than on the other, as is probably the case with *Iapetus*, the outer satellite of *Saturn*, and secondly, that it is elongated, or double, as has been assumed by M. André and others (*Astron. Nach.*, 155, 30). In the first case, the successive maxima would always have the same intensity, and would succeed each other at equal intervals which would be equal to the period of revolution. The same would be true for the minima. In the second case, if the two bodies differed in diameter, the successive maxima and minima might have unequal intensities, and if the orbit were elliptical the intervals between them would be alternately long and short. This seems to be the case with *Eros*, and the first hypothesis seems therefore improbable.

On the other hand, if the variation in light is caused by two similar bodies alternately eclipsing each other, it is difficult to see how more than half the light can be cut off in each case, and the minima more than three quarters of a magnitude fainter than the maxima. It then becomes necessary to assume that the two bodies are of unequal brightness, that they are elongated, or that we have a single body of the shape of a dumb-bell. Some observers have found the minima two

magnitudes fainter than the maxima. To account for this, we should be obliged to assume that one axis of the body was six times as long as that at right angles to it. Observations show that the light of *Eros* is continually varying, while if the case were that of a simple eclipse, as in the stars of the *Algol* type, we should expect that it would retain its full brightness for a large portion of the time.

If the bodies were of the same size, and the orbit circular, it might be impossible, from the light curve, to distinguish between the two hypotheses. The fourth of the corrections mentioned above, however, furnishes a means of distinguishing between them in any case. If the body is dark on one side, the time of revolution will equal the interval between the successive maxima, and the correction for the position of the observer will be proportional to this quantity. If then the position changes 180°, the correction will be one half the interval between the successive maxima. In the second case, the time of revolution will be double this, that is, equal to the interval between a given maximum and the next but one, so that the correction for position will now be twice as great as before, and approximately equal to the interval between the successive maxima.

Much material already exists for determining the constants mentioned above. Several of the photographs of *Eros* taken in 1893, 1894, and 1896, had an exposure of an hour or more. Owing to the motion of *Eros*, it formed a trail on each of these plates, which in some cases show distinct variations in brightness. This was noticed when the plates were first examined, but was supposed to be due to changes in the haziness of the air. As this is an easy method of discovering the variability of an asteroid, it is hoped that astronomers engaged in a photographic search for such objects will examine carefully all trails, to detect any changes in intensity. An examination of forty-one asteroid trails photographed with the Bruce telescope, seven of them on a single plate, failed to show, except in one or two instances, any change beyond that apparently due to varying atmospheric absorption. Generally, more than one asteroid appeared on each plate, and in such cases all showed the same changes in intensity.

The photographs of *Eros* taken in 1893 and 1894 failed to show any marked variations in light, and it is probable that the range was, at that time, small. The first three photographs were taken on October 28, 30, and 31, 1893, and included the same region, so that *Eros* could be compared with the same stars on all. On the first photograph it

was estimated to be 0.20 mag. fainter, and on the second 0.17 mag. fainter than on the third. The corresponding times, expressed in Julian Days and fractions following Greenwich Mean Noon, are 2,412,765.913, 2,412,767.846, and 2,412,768.890, respectively. The corrections mentioned above for velocity of light, and for the position of the Earth, have not been applied. No conclusions can be drawn from the plates taken on January 1 and 8, 1894. The plate taken on January 30, 1894, shows that the light was nearly constant during the first 30 minutes of the exposure. The Bruce plate taken on February 5, 1894, shows that the light was nearly constant during the first 12 minutes of the exposure, diminishing by about 0.4 mag. during the remainder of the exposure. A maximum is therefore indicated at about 2,412,865.622.

The plates taken during 1896 give more conclusive evidence of changes. The plate taken on April 6 showed an increase of light during the first part of the exposure, and indicated a probable but somewhat uncertain maximum at 2,413,656.890. One plate was taken on June 4, and two on June 5. The first of these images was estimated to be 0.20 mag. fainter, and the third 0.83 mag. fainter than the second. The first also indicated a maximum at about 2,413,715.702. The times of the three plates were 2,413,715.694, 2,413,716.829, and 2,413,716.919. A maximum is indicated by the plate taken on June 29, at about 2,413,740.803. The Bruce plate taken on June 30, shows a probable increase, followed by a very marked decrease, and indicating a maximum at 2,413,741.561.

The photometric measures made in 1898, and described in *H. C. O. Circular* No. 34 (*Astron. Nach.* **147**, 363), furnish an accurate determination of the times of maximum, and of the range for that epoch.

A very large number of photometric measures of *Eros* have been made since July 1900. Observations have been obtained with the 15-inch equatorial on 51 nights, the number of photometric settings each night being, in general, 32, but sometimes more. It has often been observed on 56 nights with the 12-inch horizontal telescope, 32 or more settings being made each night. Some months will be required to reduce these observations completely, owing to delay in adopting magnitudes of the comparison stars. It is hoped, however, to issue shortly another *Circular* giving the results of a preliminary discussion of these observations, and of those described above.

EDWARD C. PICKERING.

April 24, 1901.

VARIATION IN LIGHT OF *EROS*.

THE range of variation in the light of *Eros*, which has been diminishing during the spring, has now become zero. In February 1901 it was found by European astronomers to amount to 2.0 mag. Observations by Professor O. C. Wendell, with the Harvard Equatorial, showed that the range on March 12, 1901 was 1.13 mag.; on April 12 it was 0.40 mag. and on May 6 and 7 it was imperceptible and apparently less than 0.1 magnitude.

EDWARD C. PICKERING.

May 8, 1901.

NOVA PERSEI.

IT was pointed out in *Astronomy and Astro-Physics*, **13**, 201, that all the phenomena connected with the spectrum of a *Nova* could be readily explained if we supposed the appearance to be caused by an outburst of hot gases, which cooled as they receded from the star. The approaching gases being comparatively cool on the side turned toward us would present a spectrum of dark lines. The receding gases being hot on the side toward us would give a bright line spectrum. Since the direction of the velocity of the gases on the further side of the star in the line of sight was the reverse of that of the nearer gases, the latter could not mask the bright lines, and we should accordingly have a superposed spectrum of bright and dark lines as shown.

Perhaps the more generally accepted explanation of the phenomenon presented by a *Nova* is that it is due to the collision of two bodies, solid, meteoric, or gaseous, moving in opposite directions nearly in the line of sight.

There is, it appears, a crucial test of the validity of these two hypotheses, which we are now for the first time able to apply. On the latter theory, the relative velocity of the sources of the dark and bright lines must be less after the collision than while it is taking place, and while the *Nova* is at its brightest, and under no circumstances can it be much greater. On the former theory, on the other hand, while the gases are working their way through the resisting surface of the star, and heating it, their relative velocity will be less than after the surface has given way, and they are free to expand unresisted. In other words, the question is, was the relative velocity of the two sources at the time of maximum brilliancy greater or less than it was afterward ?

Nova Persei is the first of these objects whose spectrum it has been possible to study photographically at the time of maximum brilliancy. The answer to our question is given very definitely by the *Harvard Circular* No. 56. It there appears that upon the night of February 23, the maximum, the spectrum consisted of a bright band crossed by dark lines. Of these, the hydrogen lines were seen, on careful examination, to be bright on the side of greater wave-length. That is to say, the relative velocity of the sources of the bright and dark lines was small. On the next night, however, they were well separated, and the spectrum presented the usual appearance of a *Nova*. At the same time the brilliancy of the object was appreciably reduced.

From these facts I conclude that, as far as these observations go, the collision theory has been rendered untenable, and the explosion theory has been corroborated.

WILLIAM H. PICKERING.

HARVARD OBSERVATORY,
Cambridge, Mass., March 21, 1901.

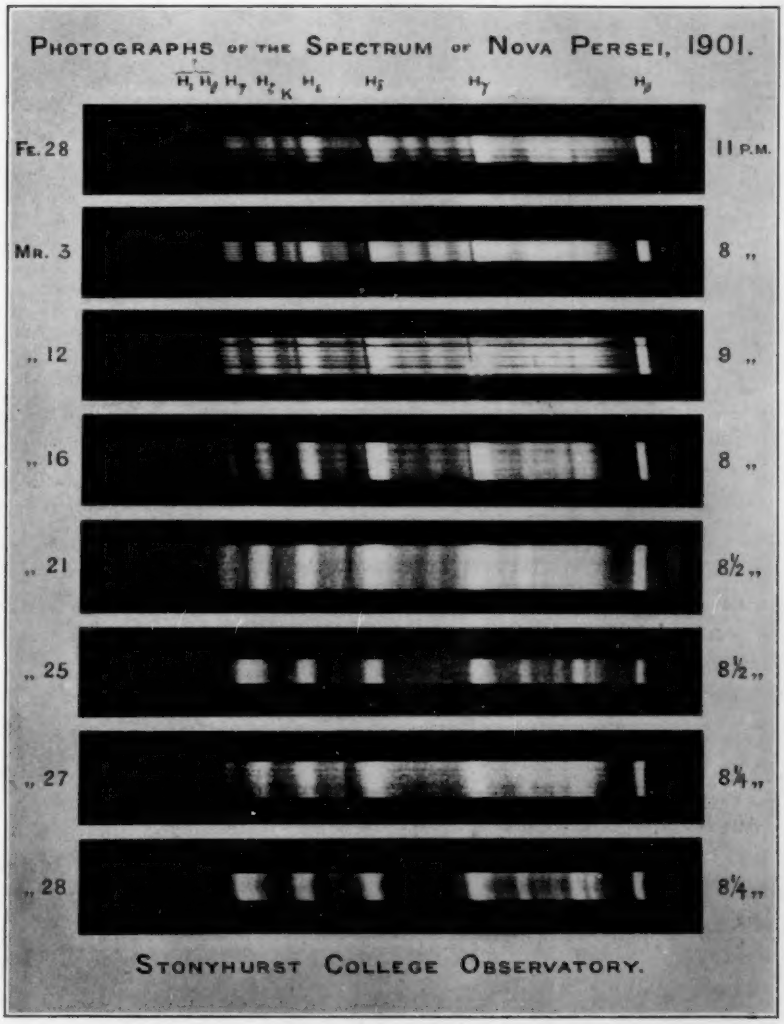
NOVA PERSEI. FEBRUARY 28 TO APRIL 4: STONYHURST COLLEGE OBSERVATORY.

THE finer details of the negatives are mostly lost on the enlargements (Plate X). But a feeble central shading of bright $H\beta$ can be detected on all the dates except March 25.

More details appear on the photograph of March 12, which is the best plate for definition, but is disfigured at $H\gamma$ by a flaw on the film. The double character of the dark H lines is well seen on this enlargement in γ, δ, ϵ, ζ, and fairly well in η.

The variable spectrum corresponding with the three-day light-period is shown in the last four spectra. The photograph of the 27th was not very successful; but on examination it will be found to be closely the same as the better photograph of the 21st. These dates are the days preceding a minimum of the light curve. The spectrum on the minimum of the 22d has been omitted; but it is in every detail the same as that of the 25th, so that the three minima are represented by the two photographs of the 25th and 28th, which show a remarkable extension of bright $H\zeta$ nearly covering the entire space up to $H\eta$, and the bright blue bands asserting their gaseous origin.

PLATE X


PHOTOGRAPHS OF THE SPECTRUM OF NOVA PERSEI, 1901.
Hδ Hγ Hβ
FE. 28
MR. 3
" 12
" 16
" 21
" 25
" 27
" 28
11 P.M.
8 "
9 "
8 "
8½ "
8½ "
8¼ "
8¼ "
STONYHURST COLLEGE OBSERVATORY.

On March 31 and April 3, supposed minima, the sky was overcast. On April 4 a good photograph showed the same spectrum as on March 27 except that $H\zeta$ was marked by a strong line of maximum brightness considerably to the violet side of its wave-length center. The star was brighter; its continuous spectrum was stronger; and the $H\zeta$ extension absent.

WALTER SIDGREAVES, S. J.

REVIEWS

Annals of the Astrophysical Observatory of the Smithsonian Institution.[1] Volume I. By S. P. LANGLEY, Director, aided by C. G. ABBOT.

IN the ASTROPHYSICAL JOURNAL for February 1895 a brief account was given of the bolometric investigations then in progress at the Smithsonian Institution. Since the publication of this paper important improvements have been made in the apparatus and in the conditions under which it is used. The effect of these changes upon the bolometric results has been marked. In fact, the experimental period of the research is so far past that it has become possible to make a long series of bolometric records of the lines in the infra-red solar spectrum upon a uniform system. The present volume contains a detailed description of the apparatus and methods employed in this research, together with an extensive map of the infra-red spectrum and a table of wave-lengths of 740 lines determined from the bolographs.

It is interesting to remember in the present connection that the development of an astrophysical observatory as a part of the Smithsonian Institution is in harmony with the ideas regarding the purpose of the institution entertained by certain prominent members of Congress at the time of its foundation. In 1838 ex-President Adams, when asked by the secretary of state as to the proper disposition to be made of the Smithson legacy, strongly urged the establishment of a great astronomical observatory. For many years Mr. Adams continued to advocate in Congress that the income of the Smithson fund for seven successive years should be used to found an observatory. Subsequently, in his opinion, the income should be employed "to promote establishments for increasing and diffusing knowledge among men." The present volume of *Annals* is satisfactory evidence that, although Mr. Adam's wishes were not complied with in the early days of the Smithsonian Institution, an observatory has nevertheless been established, which with very modest equipment has produced results of the first importance.

[1] Reviewed from advance sheets.

The volume opens with a brief historical statement, from which it appears that the work of the Observatory was begun in 1890 in a temporary shed erected immediately south of the main Smithsonian building. From time to time various additions have been made to the "temporary shed," but it still continues to be the principal Observatory building. The needs of the work were reported to Congress in 1891 by the secretary and since that time an annual appropriation has been made for the maintenance of the Astrophysical Observatory. The researches of the Observatory, which have been carried on under the general supervision of Secretary Langley, have been in direct continuation of his well-known investigations at Allegheny. Credit is given to the assistants who have been in immediate charge of the work, and particularly to Mr. C. G. Abbot, whose labors during the last few years have done much to establish the high degree of efficiency of which the results here recorded offer abundant evidence.

As might have been expected in an investigation of this kind, the early years of the Observatory were devoted to the development of apparatus and methods capable of giving the desired results in spite of the unfavorable character of the surroundings. Anyone who has used the bolometer is aware of the difficulty of obtaining good results when a high degree of sensitiveness is required. In visual observations the fluctuations due to "drift" may not be serious unless the drift is very rapid. But in cases like the present, where the galvanometer deflections are photographically recorded, it becomes necessary to eliminate the drift as far as this can possibly be done. For this purpose automatic control of the heating supply was introduced in 1896, and a cooling system, also controlled automatically, was provided in 1897. Successive improvements in the bolometer case and in the temperature control of the various resistances in the bridge circuit have finally resulted in reducing the drift to a minimum. As more and more sensitive galvanometers were constructed, the difficulty of protecting these delicate instruments from disturbances of various kinds became greater and greater, particularly in view of the fact that wagons and railway cars are constantly passing near the Observatory. The detailed description of the apparatus finally adopted, which will prove of the greatest interest to spectroscopists, is given in a later section of the volume, and will be referred to more particularly below.

Chapter I contains a short account of previous investigations of the infra-red spectrum. After referring briefly to the work of Herschel,

Lamansky, Abney, and others, Dr. Langley's early researches at Allegheny are described somewhat more fully. The solar spectrum, as mapped with the bolometer at Allegheny, ended near the band Ω, at wave-length about 2μ. In 1883 Dr. Langley conducted an expedition to Mt. Whitney in southern California, where at an altitude of 12,000 feet he detected for the first time an extensive region of greater wave-length, the detailed investigation of which forms the principal subject of the present volume. Chapter II outlines the progress of the research at the Smithsonian Astrophysical Observatory up to July 1, 1897, by which time the position of 222 lines in the infra-red spectrum between wave-lengths 0.76μ and 5.3μ had been accurately determined. Chapter III brings us to a description of the Observatory and the apparatus at present employed.

There can be no doubt that delicate bolometric work of this character, which requires great uniformity of temperature, could be done to better advantage in a building of brick or stone. To obviate as far as possible the fluctuations in temperature, which would be especially troublesome in a light wooden building, the sensitive parts of the apparatus are placed within an interior chamber, which is maintained at as nearly as possible a constant temperature of 20° C. by means of heating and cooling coils provided with a system of automatic regulation. This has proved so successful that the extreme variation within the inner chamber during twenty-four hours is frequently as small as 0°.1 C.

The immediate object of the investigation is to obtain a photographic record of the galvanometer deflections caused by the passage of the infra-red spectrum of sunlight over a fixed bolometer. A large siderostat of the Foucault type, with plane mirror 46 cm in diameter, stands to the north of the building and sends a beam of sunlight to a slit mounted upon a pier within the Observatory. After passing through the slit the rays encounter a convex cylindric mirror from which they are reflected to a concave cylindric mirror, the two being so adjusted as to collimate the beam. The parallel rays now fall upon a rock-salt prism of about 60° refracting angle, and are then reflected from a plane mirror whose silvered face forms an extension of the base of the prism. This prism mirror system, which was introduced at the Smithsonian Observatory by Professor F. L. O. Wadsworth, has the advantage that after being once adjusted for minimum deviation it will remain in adjustment when rotated, at the same time causing

the spectrum to move over a fixed bolometer strip. The image is formed upon the bolometer by a concave mirror, and a double convex cylindric lens of rock salt is interposed in front of the bolometer case in order to reduce the height of the spectrum to that of the bolometer strip. It will be understood that all parts of the spectroscopic apparatus remain fixed, except the spectrometer table upon which the prism-mirror combination stands. This table is rotated at a uniform rate by an accurately constructed driving-clock, which also moves a photographic plate in a vertical direction behind a horizontal slit. In an adjoining room a spot of sunlight is reflected from the galvanometer mirror through the horizontal slit to the sensitive plate. When, through the rotation of the prism, a dark band in the spectrum comes into coincidence with the bolometer strip, the spot of light from the galvanometer mirror moves horizontally across the photographic plate, which thus records the deflection.

The curves thus photographed accurately represent the distribution of energy in the infra-red spectrum, except in so far as they are affected by changes in the battery current, passing clouds, magnetic or mechanical disturbances of the galvanometer needle, lack of perfect synchronism in the motion of the prism and the plate, etc. The close agreement of bolographs of the same region of the spectrum is sufficient evidence that the greater part of the disturbing causes have been eliminated. The principal difficulty is that arising from the "drift." The use of a constant temperature laboratory has not proved sufficient to prevent drift. The regulation, as remarked above, is accurate to about $0^\circ\!.1$ C. Fluctuations of temperature of this magnitude in various parts of the bridge circuit are quite great enough, however, to cause large deflections. In order to keep all parts of the bridge circuit at practically the same temperature, Mr. Abbot has designed an ingenious form of bolometer case which contains not only the bolometer itself and the coils that form the other two arms of the bridge circuit, but also the balancing device with which the perfect equilibrium of the circuit is secured. The bolometer is protected from the air by a rock-salt cylindric lens which closes the front of the case. The resistance coils, which are of platinoid wire wound in a double spiral, surround a tube which contains the eyepiece for viewing the bolometer from behind. The entire case is enclosed in a waterjacket. Balancing is easily effected without opening the case.

The elimination of drift depends not only upon the constancy of

the battery and the uniformity of the temperature in the bolometer circuit but also upon the construction of the bolometer itself. Difficulty sometimes arises from the use of very thin platinum for the bolometer strip. The reviewer has found that electrolytically deposited platinum of thicknesses ranging from 0.3μ to 0.6μ frequently contains minute holes and is liable to give trouble when employed for bolometers. The experience of the Smithsonian observers has led them to employ rolled platinum not less than 1μ thick. The only flux which can safely be used for soldering is resin.

No part of the apparatus is more important than the galvanometer, and here marked advances have been made at the Smithsonian Observatory. Through successive improvements the galvanometer constant (current required to give a deflection of 1 mm on a scale at 1 m with a time of single swing of the needle of 10 s) has been reduced from 2.4×10^{-7} to 2.0×10^{-11}. In order to protect it against disturbances the needle system is suspended in an air-tight case and the entire galvanometer is floated upon mercury in a lead pan hung from a modified form of Julius suspension system. A battery of sixty storage cells protected from sudden temperature changes supplies the current. This has proved to be satisfactory, but its performance has recently been surpassed by that of a ten-cell Cupron battery.

All of these parts of the apparatus are fully described, in many cases with working drawings, in chapter III, which also explains the various adjustments. Chapter IV gives the exact procedure in preparing and comparing bolographs. An important part of the process, which furnishes a check on the reality of the deflections, should be mentioned here. After the apparatus has been set in motion and before the bolometer has been exposed, a run of several minutes is always made to determine the magnitude of accidental disturbances. If there were no disturbances of any kind and if the battery current were perfectly constant throughout this run, it is evident that the trace recorded on the photographic plate would be a straight line. In practice it is found that the line is broken by numerous small deflections, averaging about 0.4 mm. In comparing bolographs, a record of these accidental deflections is indispensable in deciding as to the reality of the less conspicuous solar lines.

Chapter V contains an interesting discussion of limitations of the method and existing sources of error in the apparatus. Here may be found statements regarding the resolving power of the rock-salt prism,

the slit-width employed in practice, a discussion of the use of an uncollimated beam, and an investigation of the loss of energy by diffraction with narrow slit. It is shown that with a slit-width somewhat less than that used (0.15 mm) the effects of diffraction would be very considerable. This result led to the adoption of a pair of cylindric mirrors in place of the spherical mirror system formerly used. In a discussion of resolving power it is concluded that bolographic resolution may in certain cases exceed the visual because of the bolometer's power of detecting differences of brightness which are inappreciable to the eye. Much space is then given to an investigation of errors arising from a variety of causes, such as shifting of the slit image due to temperature changes in the mirror supports, effect of temperature changes on the index and angles of the rock-salt prism, unsteadiness of galvanometer, drift, unsteadiness of the battery, irregularities in the motion of the plate and circle, errors of comparator observations in measuring bolographs, lag of galvanometer record, errors due to the width of the slit and the bolometer strip, etc. From the entire discussion the conclusion is drawn that the probable error in a determination of the relative angular deviation of any well-marked absorption line in the infra-red is less than one second of arc. In view of the difficulties of the investigation, this result, which is often not greatly surpassed in visual measurements with a spectrometer, may be considered extremely satisfactory.

The positions of the lines measured in the infra-red solar spectrum, together with a table of wave-lengths expressed to the nearest tenth-meter, are given in chapter VI. The plates which accompany this part of the volume reproduce bolographs of the infra-red solar spectrum made with a 60° rock-salt prism on various dates, together with "cylindrics" and line drawings of the spectrum made from the galvanometer curves. As in several cases bolographs of the same region taken on different dates are reproduced on the same plate, it is possible to make a comparison of the corresponding maxima in the energy curves. In general it may be said that the agreement of the curves is surprisingly close and that there is much less drift than is ordinarily encountered with less highly developed apparatus.

The bolographs were taken with a large rock-salt prism at the speed ratio 1 cm of plate = 1′ of spectrum = 1 minute of time. This applies to the linear spectrum shown in Plate XX, which represents graphically the results given in the table of wave-lengths. The map is

in two parts, the first extending from the limit of the visible spectrum to the Ω line at 1.8μ. The less refrangible portion begins at Ω and extends to 5.3μ, thus including the region discovered by Dr. Langley on Mt. Whitney. The solar radiation below this point is not sufficiently marked to be included in this map. Some of the bolographs, covering limited regions of the spectrum, were taken with the greater dispersion of a 60° glass prism. These curves show that certain bands which were formerly supposed to be single lines can be resolved into many fine lines. This is true of the bands ω_1 and ω_2, which are now found to be similar to the A line, both in constitution and in variability with the altitude of the Sun. The reader's confidence in the identification of the smaller deflections will be increased by the full discussion of the effect of various disturbances and the evident pains which have been taken to eliminate all possible sources of error. Such records must almost inevitably contain a great number of small irregularities, which a too sanguine observer might be inclined to consider as real lines. Some of the earlier publications regarding the Smithsonian bolographic results, as was pointed out in the article in the ASTROPHYSICAL JOURNAL already referred to, overestimated the number of solar lines actually recorded.

The present table of wave-lengths contains 740 lines measured by two observers on twenty-one bolographs. Some of these bolographs were taken with a rock-salt prism and others, of the region A to Ω, with the glass prism. Some twenty auxiliary bolographs were used to check the results in special cases. Deflections smaller than 0.4 mm, the average accidental deflection in curves made with the bolometer covered, were rejected. All of the examinations and measurements of the bolographs were made by two observers independently, and the tables include only such deflections (with a few exceptions) as were agreed upon by both observers.

In notes which accompany the tables the data for the various bolographs are given. Tables 18 and 19 contain all the measures of each line made by both observers. Table 20 contains the ordinates of the minima of the rock-salt bolographs, which serve to give an approximate measure of the relative intensity of various lines. The drift enters here as a disturbing factor and in some cases an error as great as 5 mm may occur. It may be noted, however, that many of the results contained in this table should have a far greater claim to accuracy than the very rough estimates of intensity which usually accompany

wave-length tables. In fact, the galvanometer record represents the spectrum in a much more satisfactory way than a photograph showing the lines themselves. Shadings, reversals, and other peculiarities of lines, which in an ordinary spectrum photograph are seen as it were in plan, are here shown in elevation, to the great convenience of the observer.

A full statement of the method of reducing the bolographs is next given. The most important point here is the determination of the wave-length. For this purpose a new investigation of the dispersion curve of rock salt was made with the large prism; a full account of this work is given in Part II. The angular distances from the A line of lines of known wave-length were first determined directly. The wave-lengths corresponding to the measured positions of the absorption lines were then interpolated from a curve plotted with wave-lengths and corresponding distances from A as coördinates. The table of wave-lengths of 740 lines follows.

Some space is given to a comparison of the bolographic results with the solar spectrum maps of Higgs and Abney and the infra-red metallic lines of Snow, Lewis, and others. The detailed comparison with Higgs' map, in view of the much greater dispersion of the latter, the employment of a narrower slit, and the consequent possibility of photographing faint lines which are not recorded bolographically, is satisfactory. Wave-length differences of more than two Ångström units are uncommon, and in general the agreement is closer than this. For some reason one of the double lines in the bolograph of the A series is absent, and the existence of several lines, all except one of which were marked doubtful in the bolographs, is not confirmed. It is unfortunate, probably because of the small amount of work which has hitherto been done on the infra-red spectra of the metals, that no conclusions could be drawn regarding the origin of the solar lines.

But while it has not yet been possible to determine the presence of metallic lines in the infra-red spectrum of the Sun, there is evidence that at least seven of the nine great bands are largely due to absorption in the Earth's atmosphere. In this connection an interesting discovery has been made. In the first place there seems to be evidence of a seasonal change in the infra-red absortion, typical bolographs taken in the spring and autumn resembling each other more closely than a pair corresponding to spring and summer, for example. These comparisons are very difficult to make, and some doubt may be left in

the reader's mind as to the reality of the change referred to. For this reason it is not claimed that the results given are absolute, though it is considered that they contain facts of interest. Irregular variations of absorption are more clearly indicated. A low Sun, as Dr. Langley showed many years ago, produces little general diminution of energy in the region less refrangible than 1μ, in spite of its marked effect in the visible spectrum; but the present results seem to show that great changes in local absorption can take place during a brief time interval. A table giving the relative ordinates of nearly 600 lines on plates taken in 1896 accompanies this discussion. It seems probable that if this portion of the investigation is followed up, results of value to meteorology will be established.

Part II contains an account of various subsidiary researches, the most important of which relates to the dispersion of rock salt and fluorite. This investigation deserves more extended mention than can be given here. The dispersion curve of rock salt on a scale adequate to retain the accuracy of the data accompanies the text and an interpolation table for determining the wave-length for any desired deviation is also given. A comparison of different rock-salt prisms seems to indicate that all such prisms at the same temperature and air pressure have equal refractive indices. The other investigations of Part II include a study of the accuracy of the bolometer, measures of radiation from terrestrial sources, particularly the Welsbach burner, and valuable details regarding the construction by Mr. Abbot of a sensitive galvanometer.

The Appendix discusses various dispersion formulae and their application to the infra-red spectrum, gives a determination of the constants for rock salt in Ketteler's formula, and concludes with a study of the minute structure of the absorption band, ω_1.

Secretary Langley and his associates are certainly to be congratulated on the character of the first volume of the Astrophysical Observatory's *Publications;* with this evidence of work accomplished before them, members of Congress can hardly fail to see the importance of establishing the Smithsonian Observatory on a permanent foundation. This is especially to be desired because of the fact that the U. S. Naval Observatory properly devotes little or no attention to astrophysical research. The United States should not fail to follow the lead of Germany and France by establishing a national Astrophysical Observatory under the auspices of the Smithsonian Institution.

G. E. H.